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TECHNICAL NOTE 3547

AERODYNAMIC CHARACTERISTICS OF A SMALL-SCALE SHROUDED  
PROPELLER AT ANGLES OF ATTACK FROM  $0^\circ$  TO  $90^\circ$

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Washington  
November 1955

AFM 50  
TECHNICAL



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## SUMMARY

An investigation has been made to determine the effects of airspeed and angle of attack on the lift, drag, and pitching moment of a shrouded-propeller model, having a shroud length of about two-thirds the propeller diameter, over an angle-of-attack range from  $0^{\circ}$  to  $90^{\circ}$ . Tests were made of the complete model with the propeller operating and also of the shroud and motor combination with the propeller removed. The effect of inlet-lip cross-sectional radius on the static-thrust characteristics was also studied. These tests were made in connection with the design of a vertical-take-off free-flight model and the results are presented herein without analysis as it is felt that they may be useful in the design or analysis of other aircraft.

## INTRODUCTION

Considerable interest has been shown recently in two types of vertically rising aircraft which utilize a shrouded propeller. The first of these types is termed the coleopter (refs. 1 and 2). The second is a small, simple, one-man vertically rising aircraft which is little more than an engine-driven shrouded propeller. This aircraft is operated by a man standing on a platform above the propeller. Flight-test results for research vehicles tested in the development of this general type of aircraft are presented in references 3 to 6. Additional information on shrouded propellers is needed for use in evaluating proposals for the coleopter and stand-on aircraft.

The Langley Free-Flight Tunnel Section has in recent flight tests gathered a limited amount of flight data on stability and control of a scale model of a shrouded-propeller stand-on vertically rising aircraft as reported in reference 5. It was felt, however, that, before this research was extended to full-scale aircraft, force-test data were needed for a more detailed study of longitudinal stability and trim. Consequently, a series of force tests were performed to determine the effects of airspeed and angle of attack on the lift, drag, and pitching-moment

characteristics of a shrouded-propeller model over an angle-of-attack range from  $0^\circ$  to  $90^\circ$ . The effect of inlet-lip cross-sectional radius on the static-thrust characteristics was also studied. It was felt that the results of these tests would be of assistance in the design or analysis of other aircraft with shrouded propellers or ring wings. This paper presents these data without analysis.

### SYMBOLS

$c$	chord (axial length of shroud without inlet lip), ft
$d$	shroud internal diameter, ft
$S$	projected side area of shroud, $cd$ , sq ft
$\alpha$	angle of attack, deg
$V$	airspeed, ft/sec
$\rho$	air density, slugs/cu ft
$q$	dynamic pressure, $\rho V^2/2$ , lb/sq ft
$L$	lift, lb
$D$	drag, lb
$M_{c/4}$	pitching moment referred to quarter-chord line, ft-lb
$C_L$	lift coefficient, $L/qS$
$C_D$	drag coefficient, $D/qS$
$C_{m_{c/4}}$	pitching-moment coefficient referred to quarter-chord line, $M_{c/4}/qSc$
$\eta$	static-thrust efficiency, $\frac{C_T^{3/2}}{\pi^{1/2} C_P}$
$C_T$	thrust coefficient, $T/\rho n^2 D_p^4$
$C_P$	power coefficient, $P/\rho n^3 D_p^5$

T	static thrust, lb
P	power, $2\pi Qn$ , ft-lb/sec
Q	torque, ft-lb
n	propeller rotational speed, rps
$D_p$	propeller diameter, ft

#### APPARATUS AND TESTS

A sketch of the model is shown in figure 1. The basic model had a shroud 18 inches in internal diameter and 12.25 inches long which was made of glass fiber and plastic. A two-blade propeller, turned by a 5-horsepower variable-frequency electric motor, was located midway along the shroud. The clearance between the propeller tip and the shroud was 0.06 inch. Interchangeable inlet lips with cross-sectional diameters of 0.50, 1.00, 1.50, 2.00, and 3.00 inches were provided for the shroud.

The tests were performed in the Langley free-flight tunnel which has a 12-foot octagonal test section. Inasmuch as the model was very small in proportion to the size of the tunnel, no blockage or jet boundary corrections have been applied to the data. Tests simulating the forward-flight condition were made with the propeller set at a blade angle of  $8^\circ$  at the three-quarters-radius station and rotating 6,000 revolutions per minute. The 0.50-inch-diameter lip was used in all the tests except those for static thrust. The angle of attack was varied from  $0^\circ$  (thrust axis parallel to the airstream) to  $90^\circ$  in  $10^\circ$  increments. Tunnel airspeed was varied from 0 to 56 feet per second in increments of about 7 feet per second. One test was performed over the same angle-of-attack range with the propeller removed at a constant tunnel speed of 56 feet per second.

Static-thrust tests, using each of the several inlet lips, were conducted over a range of model propeller speeds from 6,000 to 10,500 revolutions per minute in increments of 1,500 revolutions per minute. These static-thrust tests were made with the model thrust axis parallel to the tunnel axis in order to avoid the scatter in data caused by recirculation of the propeller slipstream when tests are run with the model crosswise in the tunnel.

## RESULTS

The results of the forward-flight tests are presented in figures 2 to 6. Since the propeller-off tests are intended to give some information on the coleopter configuration without a propeller, the data are presented in figure 2 as conventional coefficients based on forward speed in order that they may be used for comparisons with other wings. The results of the tests for the propeller-on configuration are plotted as functions of both  $\alpha$  and  $V$  and are referred to both wind and body axes in figures 3 to 6. These results are in dimensional terms because the conventional coefficients become inadequate when the free-stream velocity is zero, and there is no apparent advantage to using unfamiliar coefficients.

The results of the static-thrust tests presented in figure 7 indicate that efficiency increases with increasing lip cross-sectional diameter. As data for these tests were characterized by considerable scatter, the plots are the results of averaging data from several runs at each test point. The scatter was due primarily to the difficulty encountered in measuring accurately the small moments representing motor torque and to the fluctuations in torque caused by the random recirculation of air in the tunnel test section.

## CONCLUDING REMARKS

An investigation has been made to determine the effects of airspeed and angle of attack on the lift, drag, and pitching moment of a shrouded-propeller model over an angle-of-attack range from  $0^\circ$  to  $90^\circ$ . Tests were made of the complete model with the propeller operating and also of the shroud and motor combination with the propeller removed. The results of static-thrust tests indicate that efficiency increases with increasing lip cross-sectional diameter. Inasmuch as these tests were made in connection with the design of a vertical-take-off free-flight model, the results are presented without analysis as it is felt that they may be useful in the design of other aircraft.

Langley Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
Langley Field, Va., August 30, 1955.

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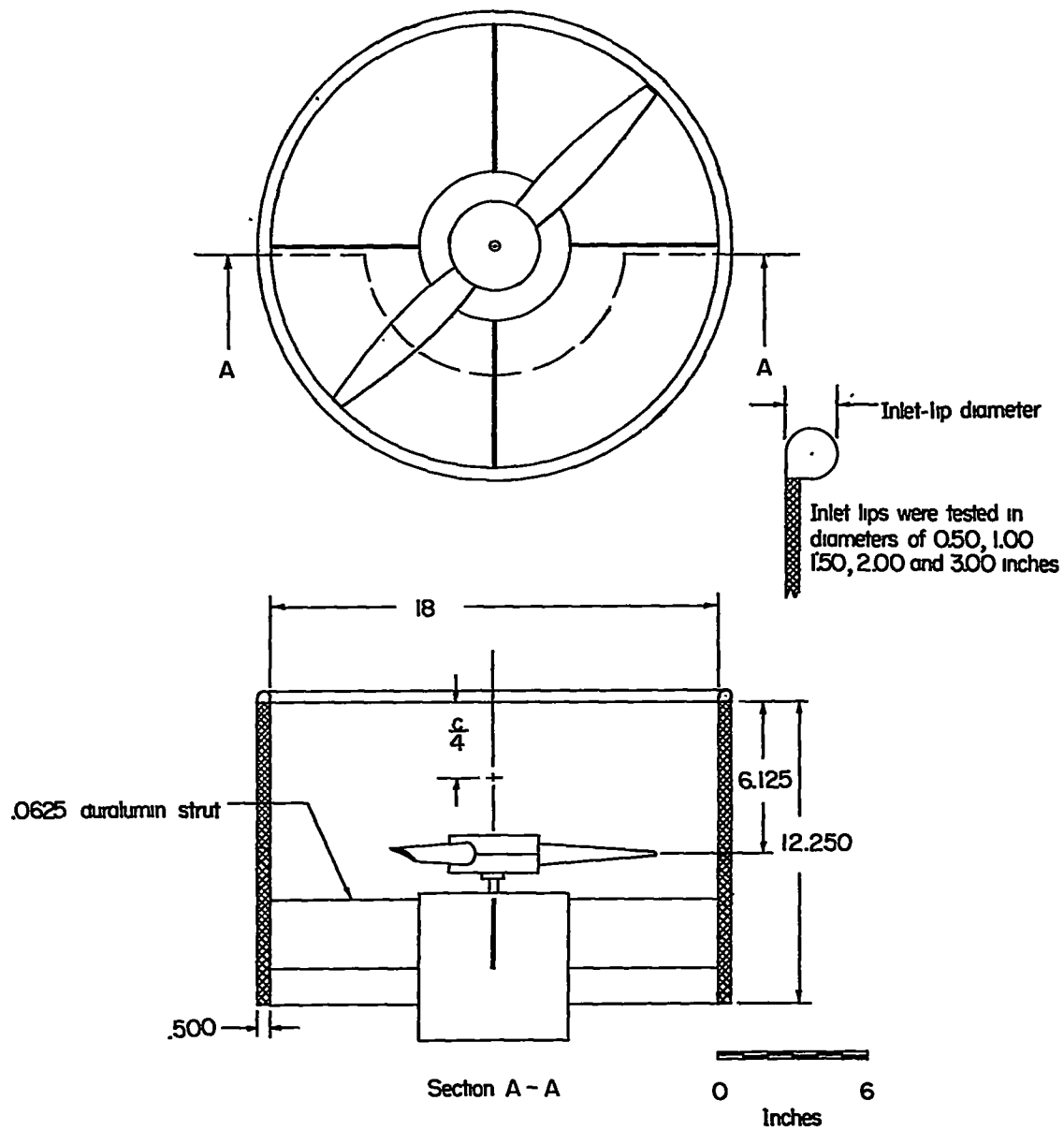


Figure 1.- Sketch of model. All dimensions are in inches.

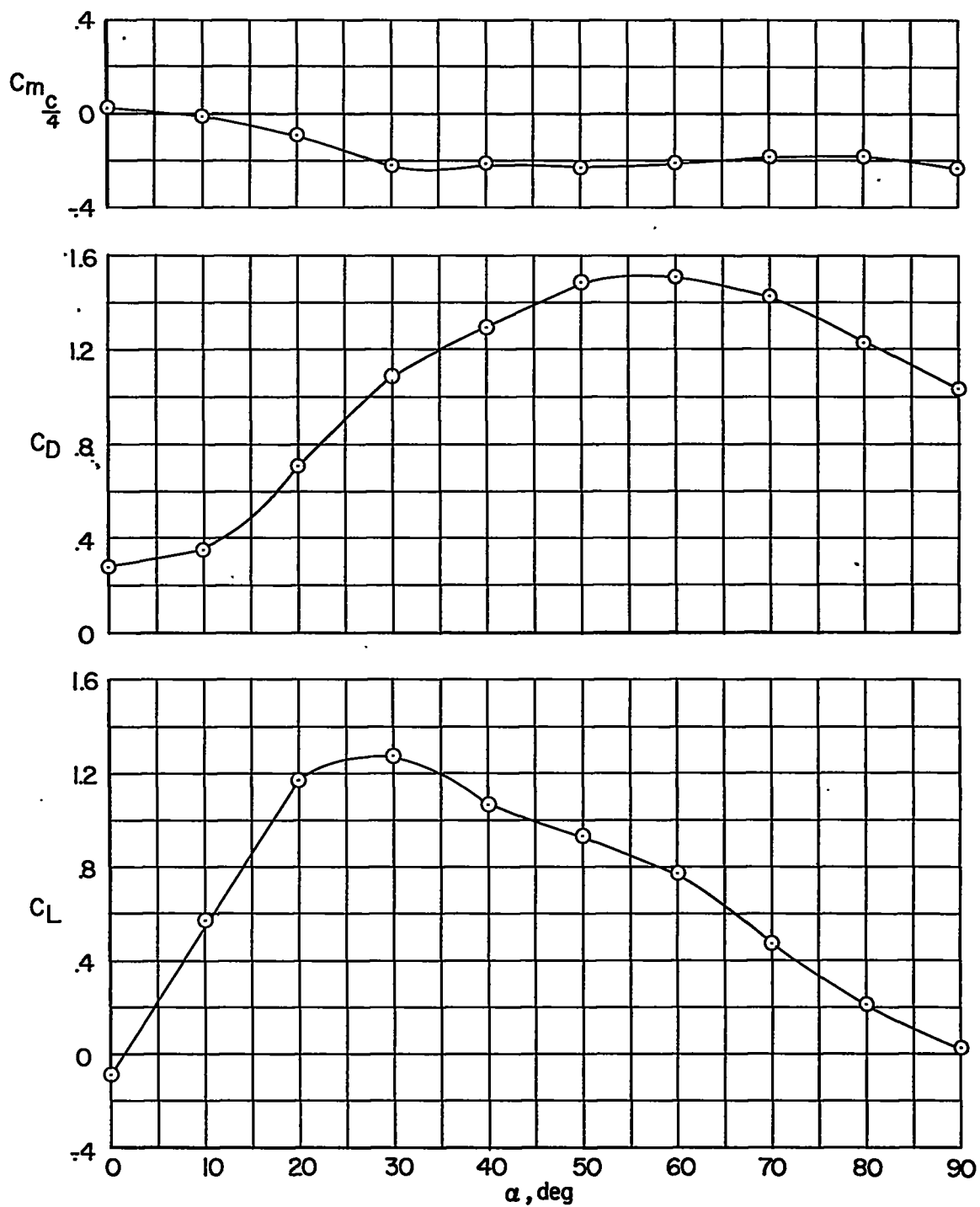


Figure 2.- Variation of lift, drag, and pitching-moment coefficients with angle of attack. Propeller off; inlet-lip diameter, 0.50 inch.



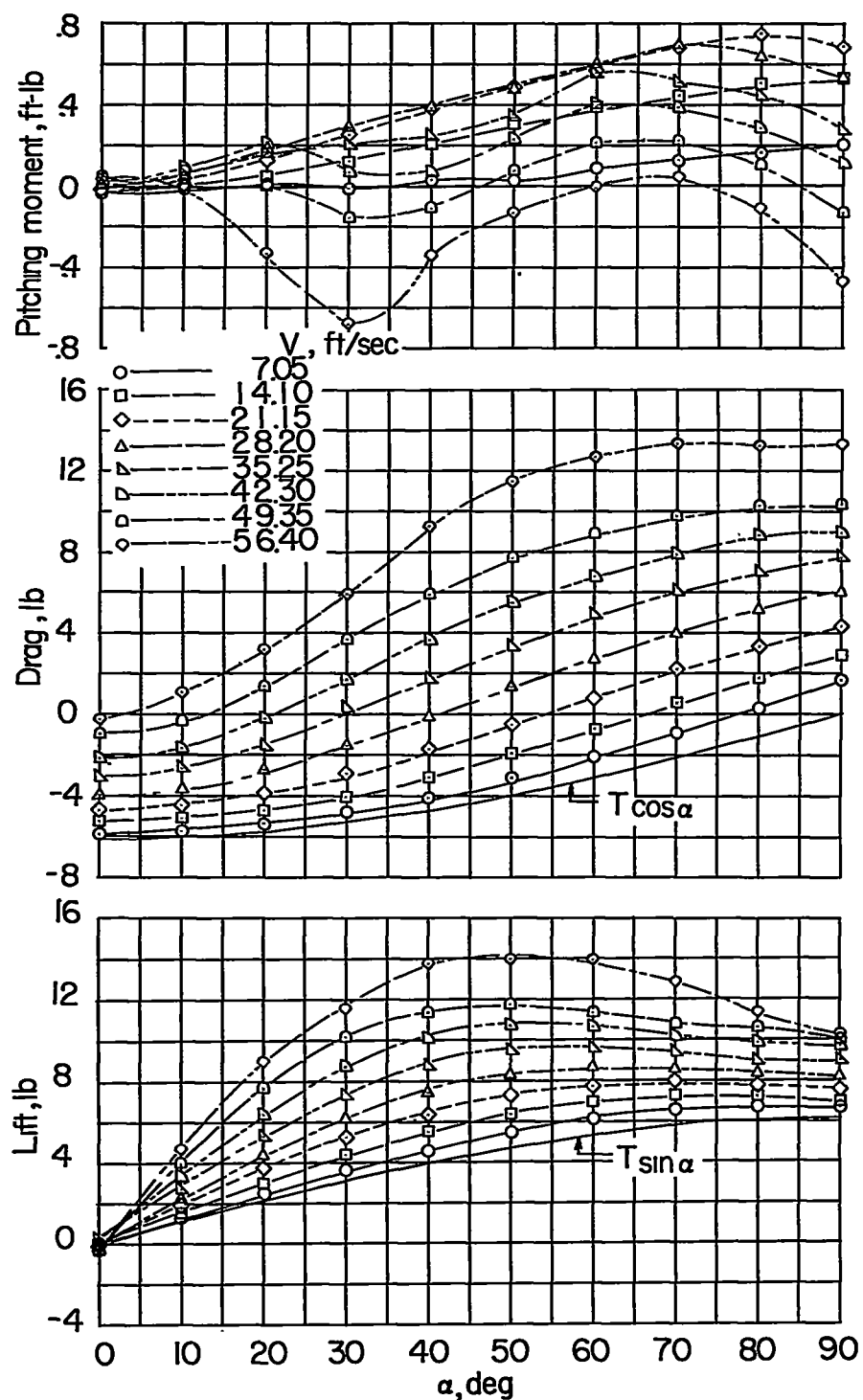


Figure 3.- Variation of lift, drag, and pitching moment with angle of attack. Propeller speed, 6,000 revolutions per minute; inlet-lip diameter, 0.50 inch; pitching moment referred to quarter chord.

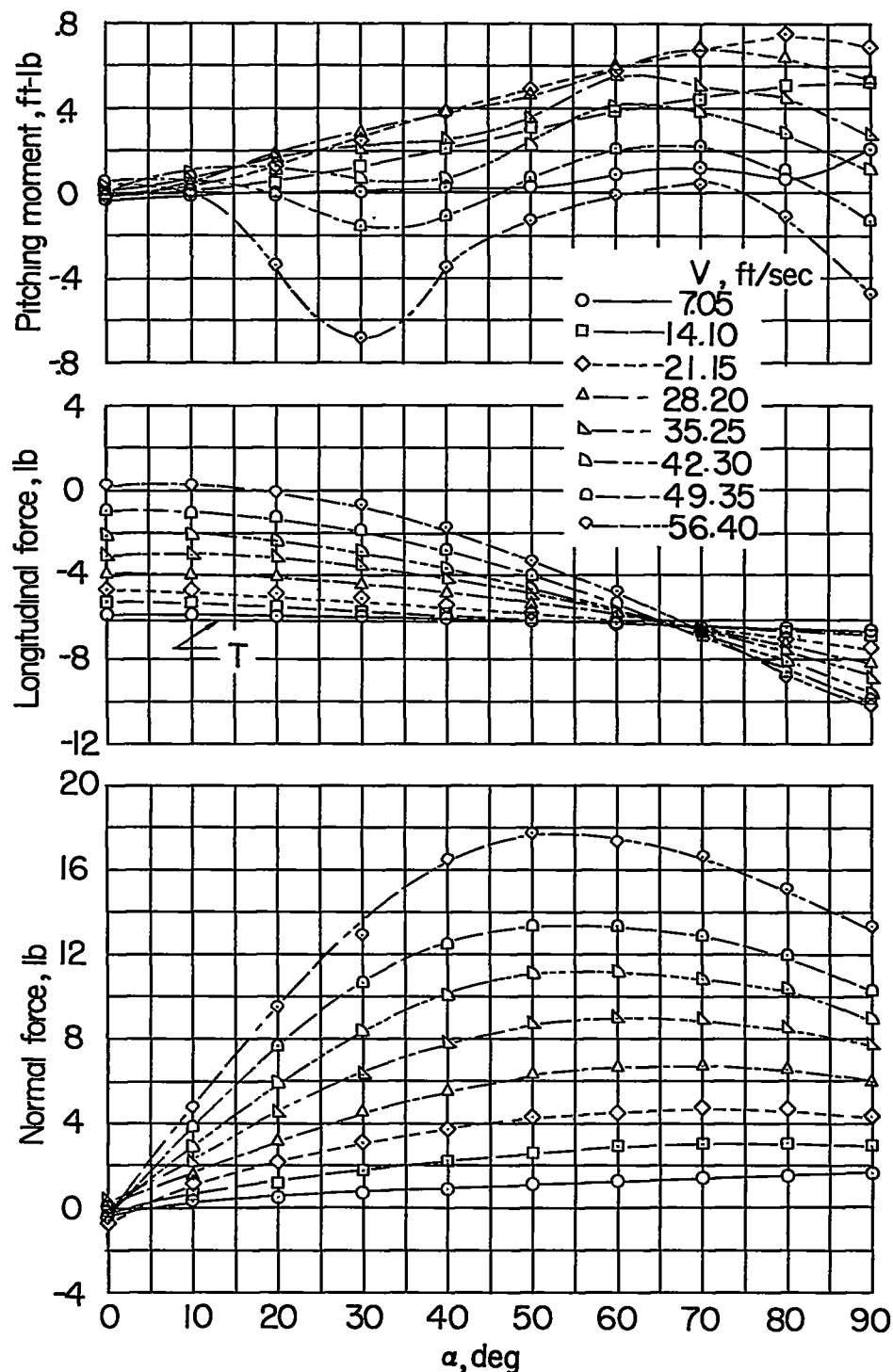


Figure 4.- Variation of longitudinal force, normal force, and pitching moment with angle of attack. Propeller speed, 6,000 revolutions per minute; inlet-lip diameter, 0.50 inch; pitching moment referred to quarter chord.

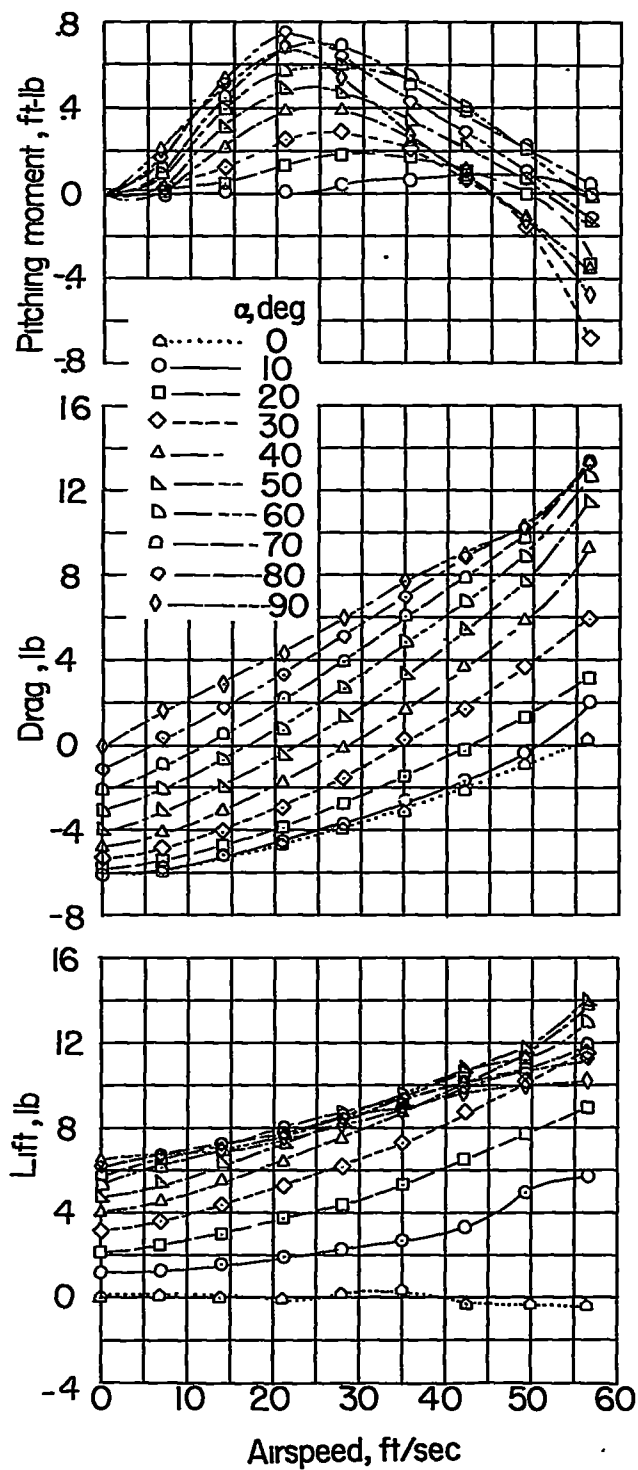


Figure 5.- Variation of lift, drag, and pitching moment with airspeed.  
 Propeller speed, 6,000 revolutions per minute; inlet-lip diameter,  
 0.50 inch; pitching moment referred to quarter chord.

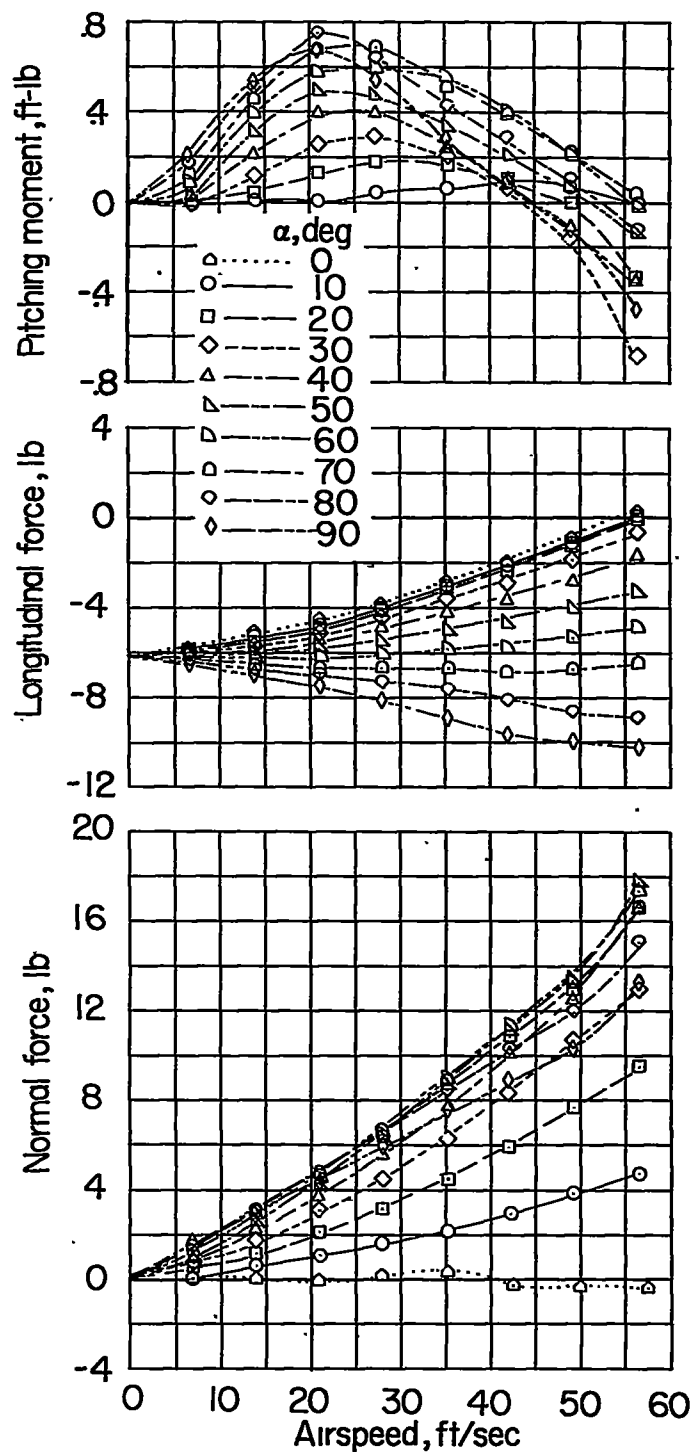


Figure 6.- Variation of longitudinal force, normal force, and pitching moment with airspeed. Propeller speed, 6,000 revolutions per minute; inlet-lip diameter, 0.50 inch; pitching moment referred to quarter chord.

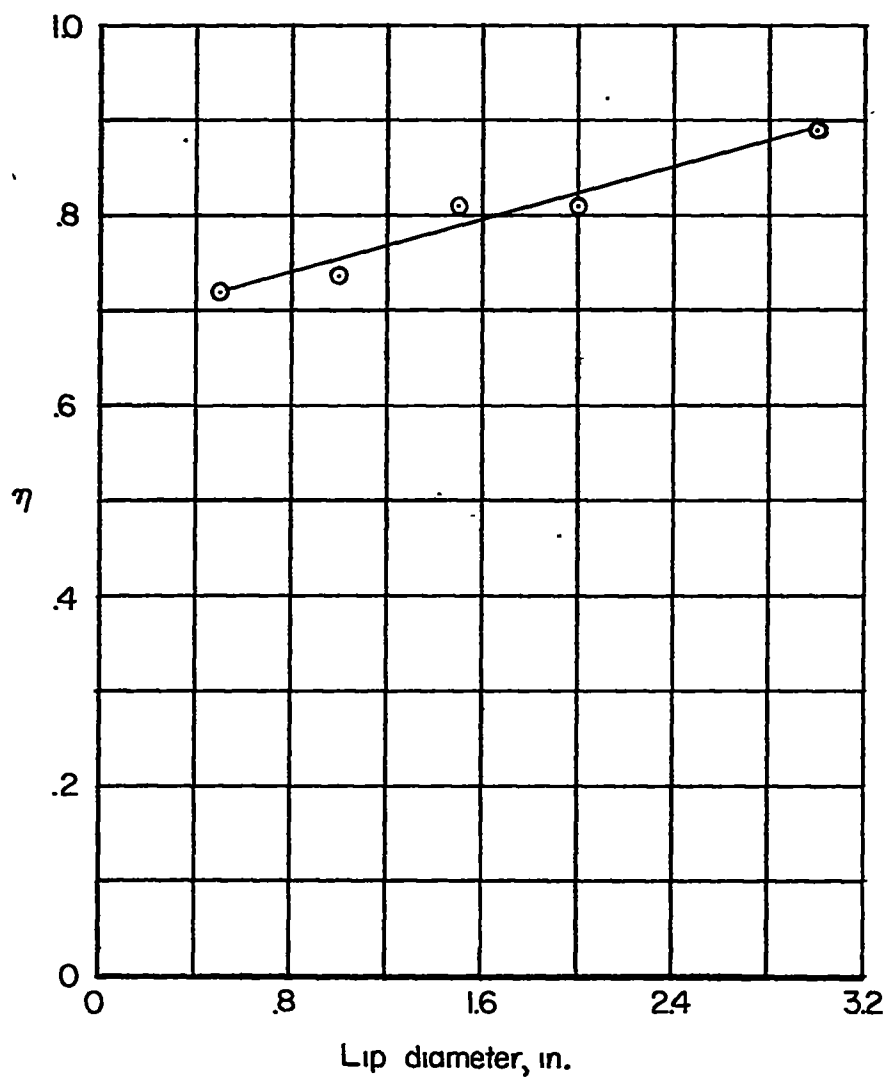


Figure 7.- Variation of static-thrust efficiency with lip diameter.